eISSN 3030-5543

HISTORIC TIMBER REPAIR TECHNIQUES TYPOLOGY IN HERITAGE BUILDING CONSERVATION; AN ANALYSIS OF MALAYSIAN PRACTICE

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Abstract: Timber has been an integral part of Malaysia's architectural heritage, contributing to the uniqueness and historical significance of its heritage buildings. As the conservation of heritage structures gains importance, the practice of repairing historic timber elements becomes paramount. This study objectives are (i) to explores the methods, challenges, and significance of historic timber repairs in Malaysian heritage building conservation (ii) to investigates the practice of historic timber repairs in heritage building conservation in Malaysia and (iii) to examine the methods, materials, and approaches employed in historic timber repairs in Peninsular Malaysia. The use of timber in traditional Malaysian architecture has made a significant contribution to the country's architectural heritage. However, the diminishing supply of historic timber resources and traditional knowledge in timber restoration pose increasing challenges to the preservation of this heritage. The research also analyzes the challenges and issues faced by conservation professionals and contractors in their efforts to maintain the structural integrity and historical significance of heritage buildings that incorporate timber elements. Data was collected through an in-depth case study of historic timber repair projects conducted across Malaysia. Data analysis includes a comparison between traditional and modern methods used in restoration, as well as an assessment of the impact of repairs on the authenticity and historical value of the buildings. The findings of this study provide valuable insight into the practice of historic timber repairs in Malaysia and underscore the importance of preserving traditional knowledge in heritage conservation. It also offers practical guidance for conservation professionals and contractors involved in the restoration of historic timber buildings. This research emphasizes the necessity of ensuring that historic timber repairs in Malaysia are carried out meticulously to

eISSN 3030-5543

preserve the authenticity and historical value of the buildings while safeguarding the dwindling resources of timber.

Keywords: Historic Timber, Replacement Timber, Repair Works, Building Conservation

INTRODUCTION

Timber has been an integral part of Malaysia's architectural heritage, contributing to the uniqueness and historical significance of the country's heritage buildings. As the conservation of heritage structures gains increasing attention, the practice of repairing historic timber elements has become crucial. Many significant heritage buildings in Malaysia have been restored through relocation for preservation by the National History Society and Museums, even before the establishment of the National Heritage Department (JWN) in 2006.

The initial awareness of the conservation movement in Malaysia began in 1945 when General Sir Gerald Templer delivered a keynote speech emphasizing the need to preserve arts and crafts.This initiative subsequently led to the formation of the Arts Council of Malaya (Peninsular Malaysia), successfully stimulating Malayan artists and craftsmen. The first heritage timber building restored in Malaysia was Istana Ampang Tinggi, an abandoned Malay timber palace that became the Negeri Sembilan Museum in 1953 (Md Ali, 2016).

To this day, conservation methods for buildings, particularly timber structures, continue to improve, seeking the most effective techniques from various perspectives. In addition to conservation concepts, cost-effectiveness is a critical factor in decision-making. However, this study focuses solely on the typology of historic timber repair techniques practiced in Malaysia. Before that, the literature review from scholars introduced three general approaches to repairs in heritage building conservation works.

The significance of optimally preserving historic timber lies in the fact that it holds historical information in physical form, serving as evidence of history, local identity, and local knowledge that is irreplaceable if lost. Moreover, it is indirectly essential for educational and research purposes for current and future generations. Therefore, the repair methods that best preserve and prolong the lifespan of these timber structures must be wisely decided upon by all stakeholders involved in the conservation of historic buildings.

Historic timber repair works are not considered the same as typical timber repairs or new construction. Based on conservation principles for historic timber structures, variability in intervention and compatibility between historic and new materials, increased use of non-invasive reinforcement materials, and reversible techniques have been observed (Feilden, 2003). Reinforcement at weak points, reversible repairs, and the preservation of structures considered valuable artefacts are the main reasons for introducing foreign materials.

In this research, an observation survey on-site, project document analysis, and interviews with experts were methods applied. Several historic timber building conservation projects in Malaysia were used as case studies. The repair techniques identified were categorized based on generalizations from suggestions by local scholars involved in the conservation of these timber buildings. The historic structure repair work is preceded by determining the best method, supported by experiments ranging from on-site simplicity to laboratory tests. While the goal of building investigation and historic building deterioration assessments is to produce perfect contract documents with comprehensive repair specifications, there are still shortcomings or disagreements regarding the scope of work that may arise during the

project's implementation. This situation is inevitable in all conservation projects as the best methods are sought to align with conservation concepts. This has led to various repair techniques being proposed to address the different challenges encountered. Additionally, some decisions can only be made on-site during the ongoing conservation work, often depending on the conservator's judgment. These unexpected situations frequently occur during the dismantling or addition of structures to historic timber buildings. At this point, newly discovered significant historical evidence may lead to changes in conservation approaches and work instructions in the contract documents. In other words, the Scope of Work (SoW) in the contract becomes more detailed as on-site work progresses. The contract content can serve as a mechanism to guide the conservation work of the building. On-site actual situations often lead to changes in the original repair plan to accommodate newly discovered factors. The specifications for timber elements and ironmongeries are mostly determined after the structure is exposed or dismantled. Hidden parts can be observed in greater detail after being separated for repair. At this stage, the best approaches and repair techniques are determined by the conservator and contractors.

Based on the literature review and various cases abroad, it can be concluded that the approaches to repair are divided into three categories: i. Repair, ii. Reinforcement, and iii. Rebuilding. Among these three general approaches, the "repair approach" is the most recommended in building conservation as it best preserves the authenticity of the building's fabric. In contrast, the "rebuilding approach" is the last option when the heritage building has experienced serious damage or deterioration, making it impossible to save except by replicating it as closely as possible to the original. Meanwhile, based on previous records and case studies, the "reinforcement approach" is the most commonly practised, where consolidation interventions are required to prolong the building's function and integrity. However, the foreign materials used to consolidate the historic structure should be identifiable, such as through markings or different colors, and must be properly documented. (Larsen & Marstein, 2016).

1.1 Timber-to-Timber Repairs

In historic timber structure repairs, the process typically involves the replacement of new timber members and the reuse of salvaged timber. Replacement of original members ensures minimal intervention in the historic structure. Sometimes, consolidation with new timber components is added to the old structure, either o address the ageing of the original structure or to adapt to the new function of the building. In many situations, except for the dismantling and reconstruction of timber structures, the structural engineer's last resort is to cut off the damaged sections and splice them with replacement timber. This means the original timber, which was initially one piece, is now divided into two pieces, connected together.

The jointing techniques are usually conventional or non-traditional, depending on the function of the timber member. Essentially, the direction of the force borne by the member is taken into account, for instance, tensile force for columns and bending force in beams (D. Yeomans, 2003). In certain cases, structures that were built to remain intact may likely be damaged or broken if dismantled. Conservators take the initiative to apply jointing techniques by splicing new timber with the original in situ, to replace the original timber parts that cannot be salvaged due to severe deterioration.

Replacement with new timber is usually carried out using the same species as the original. The use of other timber species but of the same or closest grade is considered an alternative when supply and cost become limiting factors. This approach is consistent with practices worldwide, as recommended by ICOMOS (2017). Park (2013) further adds that using the same timber species results in similar behaviour towards weathering and biodegradation. Thus, this ensures structural unity and perfection in design, while also allowing for uniform ageing processes in the future (Park, 2013).

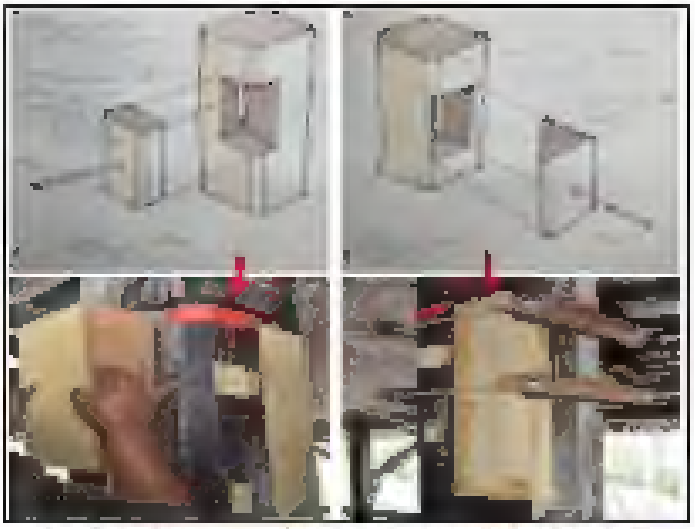

Figure 1: An example of timber-to-timber in-situ repair is planned using the carpenter's hand-drawn sketches. The joint between the replacement and historic timber columns is secured with adhesive and temporarily clamped until it cures. (Source: Ibrahim, 2019)

The concept of authenticity is always considered when restoring historic structures that face material shortages. The original techniques and methods are also applied or at least documented for reference (Jabatan Warisan Negara, 2017). However, when connecting new timber with original timber, jointing techniques must be determined on-site. Various techniques are employed to suit different on-site situations, such as the position of the member in the building and the forces it bears.

In Malaysia and many Asian countries, traditional buildings are constructed with future planning for dismantling and reinstallation. In Japan, this practice is rooted in religious beliefs (ICOMOS, 1994). In Malaysia, the practice of dismantling for reinstallation typically occurs due to changes in ownership or relocation to a new site. In the past, relocating a house was a social activity within the local community. In certain cases, when the new site was nearby, the house was lifted as a whole and moved in one piece with the help of a large group of villagers. However, today, dismantling and reinstallation are more commonly practised for conservation reasons (Muhammad et al., 2024). The reinstallation and relocation process involves minor repairs and refurbishment of the timber components. One of the main reasons for this is that the dismantling process can sometimes cause damage to both structural and non-structural components of the building (Muhammad et al., 2024).

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1.2 Timber with Foreign Material Reinforcement

In some cases, historic timber structure repairs involve the use of foreign materials, meaning that engineering techniques are applied to the original structural members to enhance their strength (Ross, 2002; Yeomans, 2008). These foreign materials are typically steel, in the form of plates, I-beams, or other sectional shapes. Steel is the most commonly used material in building conservation in Malaysia. There are records from abroad documenting the use of carbon fibre materials in timber repairs (Yeomans, 2008). Unlike timber-to-timber repairs, those involving foreign materials may require the involvement of other professionals such as engineers, blacksmiths, and others. Changes in the appearance of the building are expected but can be acceptable as long as they are minimal and comply with conservation principles(ICOMOS Singapore, 2017).

Several classifications of repair techniques have been introduced and are considered appropriate for addressing building issues. Most of the challenges in conservation work involve retaining the original elements of a building, even when their function has deteriorated. Therefore, retention is achieved through the reinforcement of weakened structures. Consolidation often involves the use of foreign materials as new structural members. New members using foreign materials are classified into several roles, as listed by various scholars (English Heritage, 2012; Insall, 1975; Larsen & Marstein, 2016; Russell, 2016; Yeomans, 2008):

i. **Reinforcement of the original timber**: This is typically done for simple reinforcement of timber members with insufficient load-bearing capacity and is also used to connect the new with the old, where parts of the members are cut due to damage/decay.
ii. **Replacement of the original timber**: This repair method is commonly used when timber members have decayed ends. The advantage of this approach is that less of the original material is lost, but the change in appearance is noticeable.
iii. **Supplementary support to the original timber**: Foreign materials either work independently as supplementary support to the original timber or function similarly to the original structure, altering its structural behaviour. However, such supplementary structures are not necessarily made from foreign materials (they may also be timber)

Figure 1: The additional structure consolidation by steel braces on the columns of Istana Satu was once relocated to the Malaysia National Museum compound (Author, 2019).

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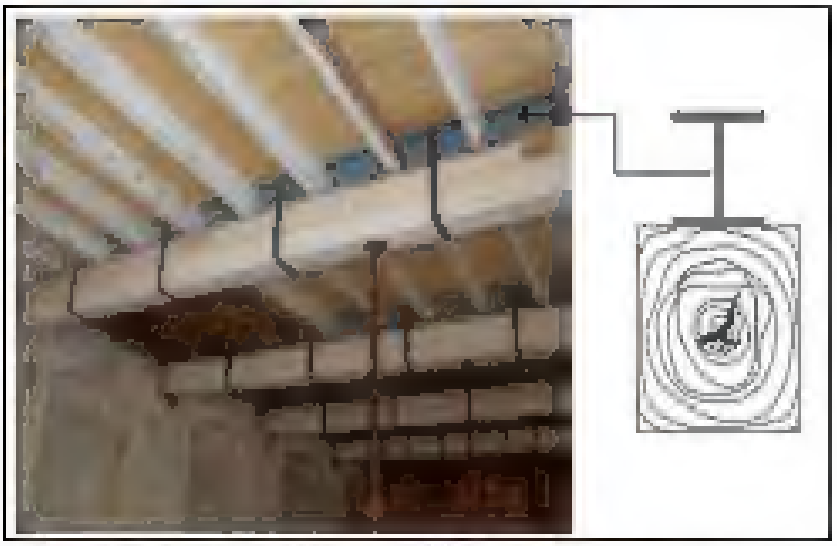

Figure 4: Reinforced timber beam using steel I-beam on the compressed area. Modified from Corradi et al. (2019) and D. Yeomans (2003).

Apart from steel, epoxy resin has been used in the repair and reinforcement of historic timber since the 1960s in Europe (Insall, 1975). Insall (1975) further mentions that epoxy resin possesses properties such as low curing shrinkage, good chemical resistance, strong adhesion, the ability to fill small gaps or cracks larger than 4mm, and sufficient strength to replace timber. In general, resin performs better than timber in joints. When maximum load is applied to a joint, cracks typically occur in the timber rather than in the resin adhesive. Epoxy resin can be used as an adhesive, a consolidant, and a replacement material for decayed timber (Ross, 2002). Consolidation with epoxy resin is achieved by controlling its viscosity, allowing it to penetrate the timber and fill cracks and gaps in the timber patina. Repair techniques involving resin are often conducted on-site (in-situ). Timber structure reinforcement using epoxy resin does not experience significant deterioration over time. However, its drawback is the dark appearance of the epoxy resin, which becomes visibly prominent. Timber reinforcement with epoxy resin is often combined with other reinforcing or replacement materials, such as stainless steel, to complement partially decayed timber components, usually occurring at the ends (Figure 7).

Figure 6: The Epoxy resin repair to the end of a beam consolidated and replaced the missing part (English Heritage, 2012).

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Figure 7: Stainless steel rods reinforced into the rafter. (a) preparing the holes to insert the rods in timber; (b) Stainless steel rods in their position; (c) resin casting in custom temporary moss (Corradi et al., 2019).

Based on the case studies conducted, there are no records of conservation repairs involving the use of epoxy resin. In Malaysia, resin has not been a preferred choice, possibly due to contractors' limited understanding of the material. Additionally, carpenters often rely on more familiar materials and their own trusted methods for timber work. According to English Heritage (2012), temperatures above 40°C can cause the resin to soften and lose its strength, making this material less suitable for use in hot climates. Many buildings experience high temperatures in roof spaces. However, there are records of repair works using natural resin, serving only as a filler to tidy up joints and seal holes or cracks in the timber while adding durability in high-humidity environments (Saad, 2019). The use of natural resin, in this case, does not involve timber reinforcement but rather serves as a refurbishment or minor touch-up.

3.3 Replicate and Rebuilt as Original

A replica is an exact copy of a building or part of it (Orbasli, 2008). In timber building conservation, the replication of building parts or, in major works, the rebuilding of the whole or part of the building is considered a last-resort conservation approach. Ideally, replication and rebuilding work should use the same timber species and design profile as the original. Similar remaining parts of the building are often used as samples for replication. Additionally, historical records such as blueprints and photographs can be other references to guide the process.

Replication work is conducted when the timber members have deteriorated to the point where they can no longer function structurally and cannot be effectively repaired (ICOMOS Singapore, 2019a). Apart from replacing damaged parts of the building, they are sometimes created for display purposes to save vulnerable values. Such decisions are based on value judgments, where the craftsmanship is potentially facing threats of severe weathering, theft or vandalism threats. The original parts were moved to a safer museum condition to preserve and still be appreciated (Orbasli, 2008). Although replication does not represent the authenticity of the heritage building in many aspects, it complements the architecture by restoring building's original appearance. Physical authenticity, such as replaced materials, copied styles, and possibly craftsmanship, can be replicated. However, the historical value, memories, and embedded evidence are lost. Thus, replication is often seen as a last resort in conservation efforts.

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Figure 8: Some of the replaced timber lattice members, which remain unfinished, were replicated based on the original ones that are still intact (Author, 2017).

Aside from replication work on building parts, the complete or partial rebuilding of a destroyed building is also considered a last-resort option to preserve historical and cultural evidence. Rebuilding should, as much as possible, replicate the original appearance of the building based on remaining information such as photographs, old blueprints, and oral accounts from senior citizens. Timber buildings are constantly exposed to the risk of fire and tend to deteriorate more quickly than masonry buildings. Based on experiences in Malaysia, the Sultan Suleiman Club Building in Kuala Lumpur is one example of a timber structure that was partially rebuilt in 2007. The Sultan Suleiman Club, established in 1909 in Kampung Baru, Kuala Lumpur, holds historical importance as the oldest and most prominent club specifically founded for the Malay community (Jafri Merican Architect, 2007).

Figure 9: One of the timber blocks of the Sultan Suleiman Club, rebuilt in 2007, referred to an old photograph from 1947 to estimate the scale of the building (Jafri Merican Architect, 2007).

METHODOLOGY

The methodology used to identify historic timber repair techniques in the conservation of Malaysian heritage buildings primarily involves analyzing contract documents, implementation records, and final project reports. These three documents contain

information about the repair work on timber elements across three phases of the repair process. The first phase involves identifying the type of timber damage in the building and determining the necessary repair work by analyzing the contract documents. The second phase focuses on the implementation of the repair work outlined in the contract documents. This phase is the most crucial for data collection in this research, as it includes analyzing the repair methods applied. During this phase, several variations of repair work were identified, which were decided on-site during the conservation project. This occurred due to two main reasons: firstly, the discovery of newly found damage on-site that was not mentioned in the contract documents, and secondly, the adoption of improved and more efficient repair methods agreed upon by all parties involved. Typically, these variations aim to ensure minimal intervention in the sensitive old structure. The third phase involves analyzing the final project report to confirm that the repair work was completed successfully and that the outcome met the goal of preserving the authenticity of the historic timber structure. Additionally, an in-depth observational survey is conducted throughout the conservation project's execution, and interviews with the respective conservators are carried out to validate the data obtained from document analysis and observational surveys. A total of five heritage buildings in Malaysia have been selected as case studies. Based on the survey, several typical timber repair techniques applied in Malaysia have been identified.

FINDINGS AND DISCUSSION

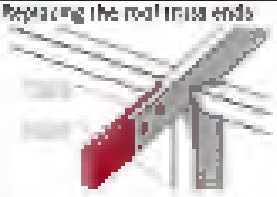
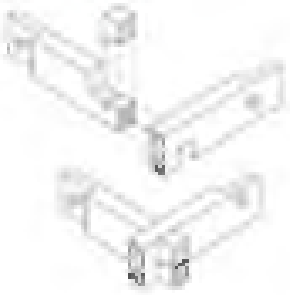
Based on the survey, it was found that the repair techniques used are closely related to the type of damage sustained and the level of deterioration of the structure or timber components in a particular heritage building. In Malaysia, various factors contribute to the degradation of historic timber. The most common forms of damage are due to prolonged exposure to moisture and termite attacks. Furthermore, the selection of timber species used in construction varies. More durable and high-strength timber species are used for the main structural elements of a building, such as columns and beams, while timber with moderate strength is used for non-structural elements like doors, windows, and walls. There are three main approaches to timber repair in heritage conservation, namely Repair, Reinforcement, and Rebuilding (Larsen & Marstein, 2016; Yeomans, 2008).

i. **Repair Approach** involves replacing damaged timber with new timber or refurbishing members that are still sound.
ii. **Reinforcement Approach** involves the introduction of foreign materials to enhance the structural integrity of original members that are weak or have failed. Based on findings from all three case studies, steel components were to reinforce original members that were either weakened or damaged.
iii. **Rebuilding Approach** is the last resort for timber members that are severely damaged and beyond repair. This reconstruction is based on documentary evidence such as original building plans, historical photographs, and memories. In Malaysian conservation practices, it is common to replace a timber member by replicating another member that remains in the building and is believed to have the same profile.

Through the case study research conducted, these three historic timber repair approaches have been further detailed into specific repair techniques that are specific to the Malaysian

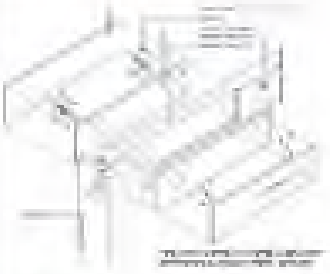
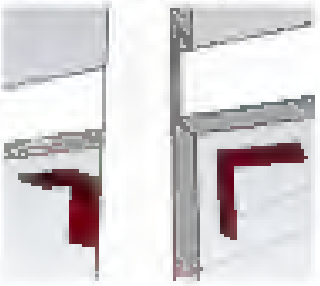
context. The techniques obtained from the survey conducted on all case studies are addressed in Table 1.

Table 1: Historic Timber Repair Approaches and Techniques Practiced in Heritage Building Conservation in Malaysia

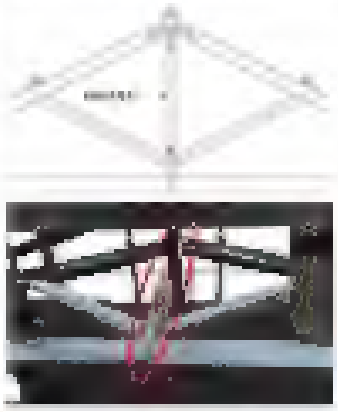
Historic Timber Repair Approaches from Literature Review	Historic Timber Repair Techniques Obtained From The Research Surveys		Recommended Situation to Apply	Examples of Repair Techniques Found in Case Studies	
Repair timber-to-timber repair using the same species or the same group of replacement timber as the original (Lourenço, 2014; Park, 2013; Designer, 2012)	I	Refurbish / Refinish	Applied on good condition parts with minor repairs, localised and refinished	Recarpentry work on door leaves 	The old finish is scraped off to prepare the surface for a new layer
				Refixing with natural resin and structure (wood)	The joining gap, small hole and crack are refixed with natural resin mixed with wood dust as putty 
	II	Cut & Joint	Applied to replace the original partially decayed parts with new pieces by carpentry jointing	Replacing the rotten column part 	Rotten timber was found at the joint between the column and the concrete stump. The joint was replaced by cutting away the affected section and connecting it with new timber. The joint was fastened with steel bolts, which were then concealed.
				Replacing the roof truss ends 	The decayed section at the end of the roof truss was cut off and replaced with new timber that matched the original species and dimensions.
	III	Construction Modification	Applied when an alternative construction methods necessary to improve the replacement timber	Jointing modification on the affected beam 	The original beam, which was severely damaged, needed to be replaced with new timber. The connection between the two beams was originally in the form of a hook. To minimise structural intervention, the replacement was carried out in-situ, and modifications to the hook connection were necessary because the installation orientation differed from the original construction.

				New jointing was created on the beam	The decayed beam was originally a single piece with both ends meant to be embedded in the columns. The beam had to be made in two parts with a joint in the middle. The new was lightened with timber keys (green) and fastened with iron bolts. The splitting was necessary because the beam was positioned between two fixed columns the columns were not removed to minimize structural interruption which could have caused damage to other timber members attached to them
	1a	Splicing to	Applied on a partially or structurally decayed part. Commonly to structural work replaces the decayed portion with new timber by lining	Decayed column repair	The decayed section was removed and shaped to fit the replacement. Timber must be of the same type with the grain orientation aligned with the original timber to ensure long-term durability
				Splicing new timber at the joint	Splicing new timber to the joint of the original structure strengthens the connection while replacing the decayed portion
	e	Relocate /Replacing	Decisions are made when a building needs to be removed or replaced and some repairs are necessary.	Dragging a house with in a short distance.	The building is moved on a new location using a prepared steel rope (top) and pulled with a chain hoist (below). This technique is only used for relocating buildings over very short distances

eISSN 3030-5543

				House lifting by manpower 	The comprehensive lifting activity is conducted to relocate the house to a new site. First, non-structural elements such as doors and windows are temporarily removed to reduce the weight of the house.
				Dismantle the structure for reinstallation 	The components of the house are dismantled one by one to facilitate transportation to the new site for reassembly. Each removed component is marked for guidance during reinstallation.
Reinforcement: Engineered techniques with foreign material applied to the original structure member to improve the strength performance (Rao, 2002; Yeoman, 2008).	vi	Foreign Material Reinforcement	The Metal/ Timber consolidation by using foreign components attached/ reinforced on the weakened timber.	Steel plate reinforcement 	Custom steel plates were clamped and fastened with nuts on both sides of the cracked beam for reinforcement. This technique avoids replacing the beam, which could cause more severe structural damage.
	vii	Transferring Loads /Support	Additional component to support/ take over the loads when the original timber structure performs.	Additional steel brackets support 	Steel L-brackets (red) are attached with screws to transfer the building load from the beam to the column, bypassing the mortise-tenon joint, which is suspected to be weakened. The purpose is to avoid damaging the joint.
				Additional rectangular hollow section steel 	An additional rectangular steel section (red) is attached to the original timber beam to provide extra strength to the joint, allowing it to support the new building function with the added load.

eISSN 3030-5543

Refurbish: An examination of a building or part of it; Replacement using similar timber species and grain (CCDMCS Singapore, 2015a; Orbasli, 2008).	yes	**Replication**	This method is applied when the original is damaged or missing. Replace the original roof with the same one by referring to the remains as a sample or using available evidence such as photographs, old blueprints and old citizen's information.	Replication of roof, Singapore 	The roof's rafter and purlin has been replaced with new timber from the same species. The dimensions and design are replicated from the original roof. The original roof (blue) has been removed. The replacement timber is from the same species.
				Rebuilt of the staircase handrail and balustrade 	The rotten handrailing and balustrade were rebuilt based on the original design. Several components that were still in good condition were reused. The replacement timber is from the same species.

CONCLUSION

In conclusion, this research sheds light on the practice of historic timber repairs in heritage building conservation within the Malaysian context. Timber has played a pivotal role in Malaysia's architectural heritage, contributing significantly to the country's cultural and historical identity. However, the preservation of this heritage faces challenges stemming from the diminishing supply of historic timber resources and the erosion of traditional knowledge in timber restoration. This study explores into the various methods, materials, and approaches employed in historic timber repairs in Malaysia. It also scrutinizes the obstacles and issues encountered by conservation professionals and contractors in their endeavours to safeguard the structural integrity and historical significance of heritage buildings adorned with timber elements.

Through an in-depth survey of historic timber repair projects conducted throughout Malaysia, this research has unearthed a profound relationship between the choice of repair techniques and the specific types of damage experienced by timber structures or components within heritage buildings. The primary culprits of timber damage in Malaysia are long-term humidity exposure and termite infestation.

In the realm of historic timber repairs, three principal approaches emerge i. Repair, ii. Reinforcement, and iii. Rebuilding. Repair techniques involve the replacement of deteriorated timber with new timber or the restoration of structurally sound elements. Reinforcement necessitates the integration of foreign materials to bolster the structural integrity of weakened or failed original members. The survey findings reveal that steel components have been employed to reinforce compromised original members. As a last resort, the rebuilding

eISSN 3030-5543

approach is invoked for timber elements that have suffered irreparable deterioration and damage.

These three overarching repair approaches have been further dissected into specific repair techniques, with epoxy resin techniques being a less common practice in Malaysia. Nonetheless, certain cases have seen the utilization of natural resin as a putty to fill gaps and nail holes.

This research underscores the vital importance of preserving traditional knowledge in heritage conservation. It serves as a valuable resource for conservation professionals and contractors engaged in the restoration of historic timber buildings. Furthermore, it emphasizes the imperative of conducting meticulous historic timber repairs in Malaysia to uphold the authenticity and historical value of these buildings while safeguarding the dwindling resources of historic timber. In the face of contemporary challenges and changing conservation paradigms, the preservation of Malaysia's rich architectural heritage continues to be a pertinent and demanding endeavour, requiring a delicate balance between modern techniques and traditional wisdom.

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